Determining the capability of artificial intelligence in estimating energy dissipation of skimming flow regime at stepped spillways

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Abstract

Energy dissipation in stepped spillways is one of the primary goals of such structures. In this study, the accuracy of the Artificial Neural Network (ANN), Adaptive Fuzzy Neural Inference System based on the trained Firefly Algorithm utilized for optimization (ANFIS-FA) and the Gene Expression Programming method (GEP), in estimating the energy loss of skimming flow regime over stepped spillways was studied. Also, by performing sensitivity analysis, the importance of input parameters in predicting energy loss for each of the three mentioned methods was investigated. For this purpose, 154 series of experimental data were considered. The input parameters for each method include hydraulic jump, Froude number, Drop number, number of steps, Pseudo bottom slope and the ratio of the critical depth to the height of each step.

The results show that all three methods had a higher ability to predict energy loss compared to classical methods based on conventional regression methods. The accuracy of the ANFIS-FA method is slightly higher than the GEP method. The accuracy of the ANN is slightly lower than mentioned methods. However, the highest accuracy is related to the multilayer perceptron ANN with 3 hidden layers with 12, 8 and 7 nodes in each layer, respectively. In all three methods, the most effective parameter was found to be the drop number and the least effective parameter was the bottom slope.

Keywords

ANFIS-FA, ANN, Energy dissipation, GEP, skimming flow, stepped spillway

Introduction

Stepped spillways are one of many types of spillways that may be selected to facilitate the safe passage of flood waves through dams. The name of Stepped spillway is in company with significant self-aeration and plenty of flow resistance and associated energy dissipation. The cascading water over a spillway crest onto a series of steps can be categorized into two basic flow regimes; nappe and skimming flow.

Hydraulic laboratories all over the world have conducted a lot of research and put forward different empirical formulas for the hydraulic problems of stepped spillways. Rajaratnam [1] presented a method

of predicting the characteristics of skimming flow over stepped spillways. He found that for stepped spillways with a slope of 1 vertical on 0.78 horizontal, the fluid friction coefficient is about 0.18. Chanson [2] collected and summarized different research results. Cheng et al. [3] simulated air-water as a two-phase flow over stepped spillways. They found that, combined RNG, k-ε turbulence model can successfully simulate the flow characteristics over stepped spillways. Salmasi and Özger [4] used MATLAB software to simulate the energy dissipation of the stepped spillway through the ANFIS model.Theydeveloped a dimensionless equation by regression technique. They reported that ANFIS is more accurate than the non-dimensional equation. Parsaie and Haghiabi [5] investigated the effect of crest shape on stepped spillway's hydraulic characteristics.

Although physical modeling is the best solution to predict energy losses of stepped spillways, construction price and expensive equipment required for measuring air aeration can be the disadvantages of physical models. Instead, use of artificial intelligence algorithms has become more and more interesting with the growing of the computing technology.

Methodology

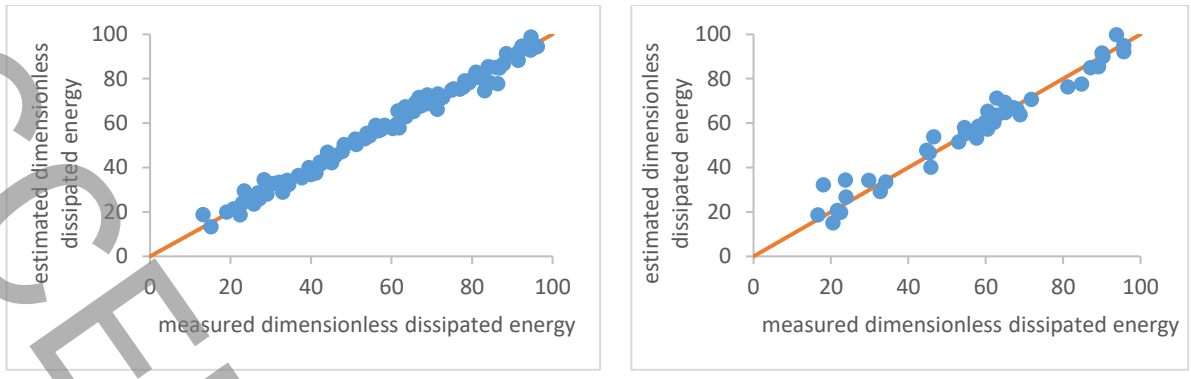
In the present study, the accuracy of 3 different intelligence algorithms for predicting energy dissipation in the skimming flow regime was examined. The algorithms investigated were Artificial Neural Networks (ANN), Gene Expression Programming (GEP), and composed algorithm of Adaptive Neuro-Fuzzy System (ANFIS) with FireFly metaheuristic algorithm (FA)(i.e., ANFIS-FA).

Five dimensionless parameters, namely Drop Number, y_c / h ratio, number of steps, Froude number just before a hydraulic jump, and step dimension, were used as input parameters to each algorithm. The best structure of each algorithm and accuracy of that were found by comparing results of predicted and measured values of energy dissipation. Moreover, the importance of each input parameter on energy dissipation was examined by sensitivity analysis.

The training and testing process for each algorithm was done by using154 experimental data sets published by Salmasi and Ozger [4]. The data range was from 0.23 to 4.21 for Fr_1, 13.1 to 96.6 for dimensionless energy dissipation rate and 3 to 50 for the number of steps. Energy dissipation was calculated based on the differences between specific energy at the upstream and downstream sides of the stepped spillway.

Results and discussion

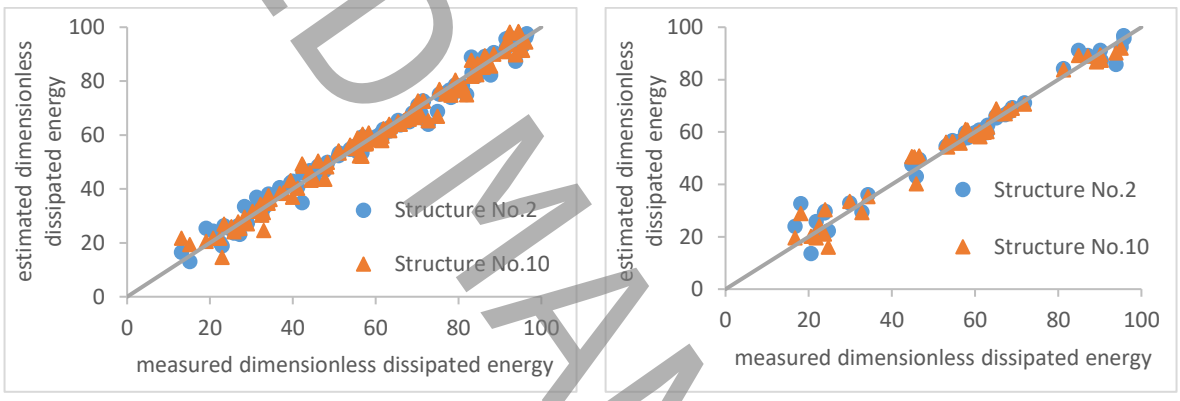
The results show that ANN with one hidden layer yields acceptable results; however, the best results were achieved when three hidden layers were implemented (R^2=0.9997 and 0.9854 for training and testing stages respectively). ANFIS-FA is another algorithm found to be robust for predicting energy dissipation, which is evident by the following results: R^2=0.99 (RSME=2.155) and 0.97 (RSME=3.796) for training and testing stages, respectively. Fig.1 shows the results of the ANFIS-FA algorithm in predicting energy dissipation of stepped spillway in the skimming flow regime.



a-training stage **b-testing stage**

Fig.1. Results of ANFIS-FA algorithm in the prediction of energy loss with all input parameters

Among different structures of GEP algorithm, two structures, namely structure No. 2 and 10, as shown in Fig.2, have approximately the same results. The best result is R^2=0.96 (RSME=4.9) and 0.94 (RSME=4.41) for training and testing, respectively. It was concluded that both ANFIS-FA and GEP can reasonably predict energy loss of stepped spillways in skimming flow regimes.



a-training stage **b-testing stage**

Fig.2. Results of the best structures of the GEP algorithm for the prediction of dissipated energy with all input parameters.

Conclusions

Energy dissipation of skimming flow at stepped spillways was predicted in this study by the use of ANN, ANFIS-FA composed algorithm, and GEP method as artificial intelligence techniques. The results show that energy loss values are well predicted using these methods. Sensitivity analysis for different input parameters reveals that among different parameters, Froude number just before the hydraulic jump, Fr_1, and drop number, q^2/gh^3, have the greatest influence on energy dissipation in skimming flow regime over the stepped spillway. On the contrary, the number and geometry of the steps leave negligible effects on energy dissipation. All artificial intelligence techniques investigated in this study showed that they not only had they similar accuracies, but also they were more accurate than empirical equations. For further research, it is recommended to use experimental data sets for the nappe flow regime over stepped spillways for evaluating the mentioned algorithms.

References

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